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# Materials Characterization of Cranial Simulants for Blast Induced Traumatic Brain Injury


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## Cranial Simulants for Reproducibility

In the quest to understand the mechanisms involved in blast-induced traumatic brain injuries that plague our returning military servicemen, materials to simulate tissues of the cranium are needed to produce models that are readily reproducible in blast studies. Object to object variation and interspecies differences are current limitations in animal and cadaver studies. Test objects that are both biofidelic and reproducible provide the opportunity to investigate dominant mechanisms at varying blast parameters. Selecting materials that are transparent allow for optical diagnostics during the blast event. Using tissue simulants, it may be possible to reproduce post-mortem diagnostics used in the clinic for adequate comparison of the observed injuries. The mechanisms elucidated from these studies may be used to inform the design of protective gear to mitigate blast injuries. Here we present the mechanical and material characterization of several materials intended for use as potential biofidelic simulants in shock tube and open field blasts for high speed optical imaging, gross observations, and post-blast analysis.

## Cavitation Markers

The mechanisms for primary-bTBI, where injury is the direct result from exposure to a shock wave, have not been independently identified. Small animal studies demonstrated vascular damage is present and it is believed that this is primarily caused by intracranial cavitation[4]. Since fluid cavitation is suspected to be partially responsible for the damage, the tissue phantoms will be imaged to look for bubble formation. Microbubbles embedded in the gel serve as cavitation nuclei and as a positive control for studying cavitation effects.

Figure 1: Expansion of microbubbles due to heat during casting at 20X

Figure 2: 200µL of microbubbles in gelatin at 20X

## Characterization Methods

Figure 3: Stretched gel on a Mark-10 Tensile Tester[5]

Figure 4: Gel sample on the SR5 Rheometer

Figure 5: Ballistic Gelatin

Figure 6: Bovine Gelatin

## Cranial Simulants Under Tensile, Compressive, and Shear Stresses

### Tensile Testing

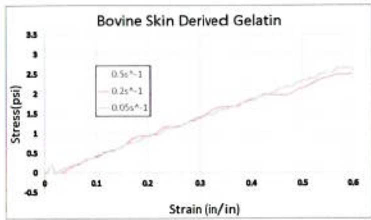


Figure 7: Average stress-strain curves for bovine skin derived gelatin at three strain rates

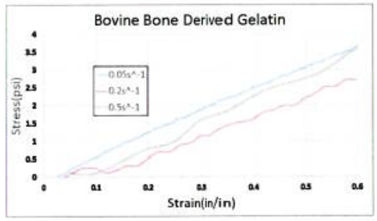


Figure 8: Average stress-strain curve for bovine bone-derived gelatin at three strain rates

Table 1. Mechanical Characterization Summary

| Strain Rate [1/s] | Avg Density [g/mL] | Avg Young Modulus [kPa] | Avg Fracture Stress [kPa] |
|---|---|---|---|
| Compression Results: Polyacrylamide Gel (PAA) | | | |
| 0.05 | 1.05 | 56.08 | 374.60 |
| 0.20 | 1.04 | 93.19 | 570.18 |
| 0.50 | 1.03 | 217.86 | 580.08 |
| Tension Results: Polyacrylamide Gel (PAA) | | | |
| 0.05 | 1.05 | 31.94 | 23.64 |
| 0.20 | 1.04 | 26.01 | 22.85 |
| 0.50 | 1.03 | 26.95 | 35.23 |
| Compression Results: Bovine Skin Derived Gel | | | |
| 0.05 | | 56.41 | 12.04 |
| 0.20 | 1.09 | 78.51 | 628.22 |
| 0.50 | 1.09 | 45.79 | 578.17 |
| Tension Results: Bovine Skin Derived Gel | | | |
| 0.05 | 1.16 | 34.43 | 28.81 |
| 0.20 | 1.13 | 30.91 | 19.37 |
| 0.50 | 1.01 | 30.10 | 19.64 |
| Compression Results: Bovine Bone Derived Gel | | | |
| 0.05 | 1.11 | 78.84 | 15.35 |
| 0.20 | 1.11 | 87.73 | 647.96 |
| 0.50 | 1.09 | 56.19 | 635.44 |
| Tension Results: Bovine Bone Derived Gel | | | |
| 0.05 | 1.09 | 46.44 | 58.83 |
| 0.20 | 1.10 | 36.62 | 99.67 |
| 0.50 | 1.08 | 48.16 | 98.68 |
| Tension Results: Ballistic Gel 10% | | | |
| 0.05 | 0.89 | 39.90 | 46.38 |
| 0.20 | 0.87 | 38.03 | 75.56 |
| 0.50 | 0.88 | 19.36 | 56.75 |
| Tension Results: Ballistic Gel 20% | | | |
| 0.05 | 0.91 | 67.63 | 69.63 |
| 0.20 | 0.90 | 45.84 | 115.97 |
| 0.50 | 0.90 | 27.48 | 125.19 |

### Compression Testing

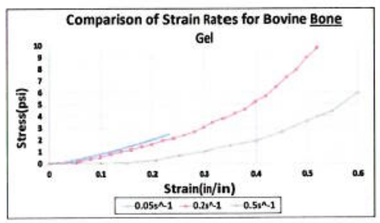


Figure 9: Average stress-strain curves for bovine bone derived gelatin at three strain rates

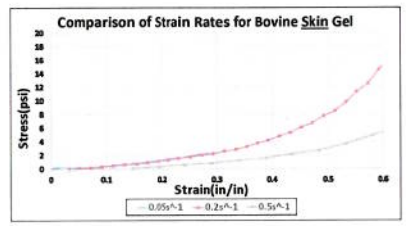


Figure 10: Average stress-strain curves for bovine skin derived gelatin at three strain rates

### Shear Testing

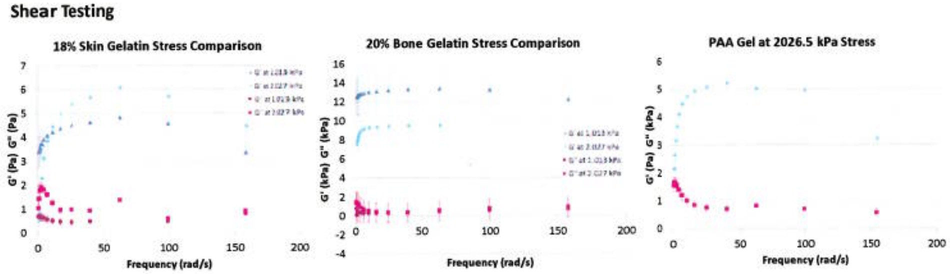


Figure 11: Dynamic shear for Bovine Skin Gelatin, Bovine Bone Gelatin and Polyacrylamide (PAA) at a given applied stress. Error bars represent calculated standard error.

## Comparison to Tissue Measurements

Table 2. Young's modulus values compared with brain tissue values from literature [11]

| Strain Rate [1/s] | Avg Young Modulus PAA [kPa] | Avg Young Modulus Bovine Skin [kPa] | Avg Young Modulus Bovine Bone [kPa] | Avg Young Modulus 10% Ballistic [kPa] | Avg Young Modulus 20% Ballistic [kPa] | Literature Value [kPa] (Rashid 2014) | Strain Range |
|---|---|---|---|---|---|---|---|
| 0.05 | 31.94 | 34.43 | 46.44 | 39.90 | 67.63 | 11.68 +/- 3.79 | 0-0.1 |
| 0.20 | 26.01 | 30.91 | 36.62 | 38.03 | 45.84 | 27.6 +/- 5.93 | 0.1-0.2 |
| 0.50 | 26.95 | 30.10 | 48.16 | 19.36 | 27.48 | 43.75 +/- 5.97 | 0.2-0.3 |

Table 3. Average shear modulus magnitude values at 25°C across a frequency range of 0-396 rad/s

| Applied Stress [kPa] | 20% Bone Gelatin [kPa] | 18% Skin Gelatin [kPa] | Polyacrylamide (PAA) Gel |
|---|---|---|---|
| 1.013 | 4.238-5.773 ± 0.96-2.96 | 8.640-10.99 ± 6.88-8.27 | 3.083-5.251 ± 0.008-0.844 |
| 2.027 | 3.833-6.378 ± 0.81-2.79 | 5.574-8.782 ± 3.53-5.55 | 3.510-6.308 ± 0.548-1.69 |

Table 4. Shear modulus values for brain tissue from literature [9,10]

| Brain Tissue | Source |
|---|---|
| 1.6-2.0 ± 0.10-0.20 kPa | Elias 2012 |
| 2.32-3.07 ± 0.40-0.49 kPa | Murphy 2011 |

## Future Optimization and Blast-Testing

Optimize bone and skin derived gelatins to simulate (grey and white matter) by reducing elastic modulus while maintaining density values

Complete the material property testing for the alginate samples and determine appropriateness as a blood vessel simulant

Characterize additional materials for skull simulant

Complete cranial object fabrication for shock tube and open field blast testing

Figure 12: Bovine Skin Gelatin in Brain Mold

Figure 13: Test Object for Blast Testing

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